NSLS-II – Status of the Life Sciences Program

Wayne A. Hendrickson
Chief Life Scientist, Photon Sciences Directorate
X6A Scientific Advisory Committee
10 February 2012

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

NSLS-II Project Scope

Accelerator Systems

- Storage Ring (~ ½ mile in circumference)
- Linac and Booster Injection System

Conventional Facilities

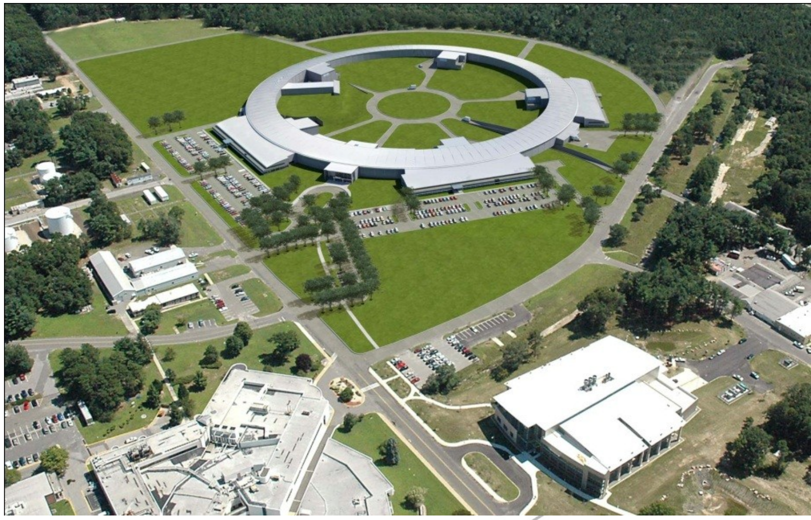
- Ring Building and Service Buildings (~ 400,000 gsf)
- 5 Laboratory/Office Buildings (LOBs) for beamline staff & users
  - 2 full & 3 shell (190,000 gsf)
- Reuse of existing NSLS office/lab space for NSLS-II staff

Experimental Facilities

- Initial suite of six insertion device beamlines
- Capable of hosting at least 58 beamlines

Research & Development

- Advanced optics & accelerator components



TPC = $912M

NSLS-II in Progress

Total Project Cost = $912M
~ 70% complete by December 2011
Accelerator magnet installations under way
Beneficial occupancy of entire floor in February 2012
Completion expected by March 2014

Key NSLS-II Project Milestones

Aug 2005	**CD-0**, Approve Mission Need	(Complete)
Jul 2007	**CD-1**, Approve Alternative Selection and Cost Range	(Complete)
Jan 2008	**CD-2**, Approve Performance Baseline	(Complete)
Jan 2009	**CD-3**, Approve Start of Construction	(Complete)
Feb 2009	Contract Award for Ring Building	(Complete)
Aug 2009	Contract Award for Storage Ring Magnets	(Complete)
May 2010	Contract Award for Booster System	(Complete)
Feb 2011	1st Pentant Ring Building Beneficial Occupancy	(Complete)
Mar 2011	Start Accelerator Installation	(Complete)
Feb 2012	Beneficial Occupancy of Entire Experimental Floor	
Apr 2012	Start LINAC Commissioning	
Jun 2012	Beneficial Occupancy of 1st LOB	
Oct 2012	Start Booster Commissioning	
May 2013	Start Storage Ring Commissioning	
Mar 2014	Projected Early Project Completion	
Jun 2015	**CD-4**, Approve Start of Operations	

NSLS-II Beamlines Underway

18 Beamline Construction Projects Underway
21 Simultaneous Endstations (SE)
28 Total Endstations (TE)

Beamlines with design and construction underway

22 additional beamlines (25 SE) have been proposed by the user community and approved by the SAC and NSLS-II but are not yet funded

Beamline ConstructionProjects	SE	TE
NSLS-II Project Beamlines		
•Inelastic X-ray Scattering (IXS)	1	1
•Hard X-ray Nanoprobe (HXN)	1	1
•Coherent Hard X-ray Scattering (CHX)	1	1
•Coherent Soft X-ray Scat & Pol (CSX)	2	2
•Sub-micron Res X-ray Spec (SRX)	1	1
•X-ray Powder Diffraction (XPD)	1	1
NEXT MIE Beamlines		
•Photoemission-Microscopy Facility (ESM)	2	3
•Full-field X-ray Imaging (FXI)	1	1
•In-Situ & Resonant X-Ray Studies (ISR)	1	2
•Inner Shell Spectroscopy (ISS)	1	1
•Soft Inelastic X-ray Scattering (SIX)	1	1
•Soft Matter Interfaces (SMI)	1	2
ABBIX Beamlines		
•Frontier Macromolecular Cryst (FMX)	1	1
•Automated Macromolecular Cryst (AMX)	1	1
•X-ray Scattering for Biology (LIX)	1	1
Type II Beamlines		
•Spectroscopy Soft and Tender (NIST)	2	6
•Beamline for Materials Measurements (NIST)	1	1
•Microdiffraction Beamline (NYSBC)	1	1
TOTAL	**21**	**28**

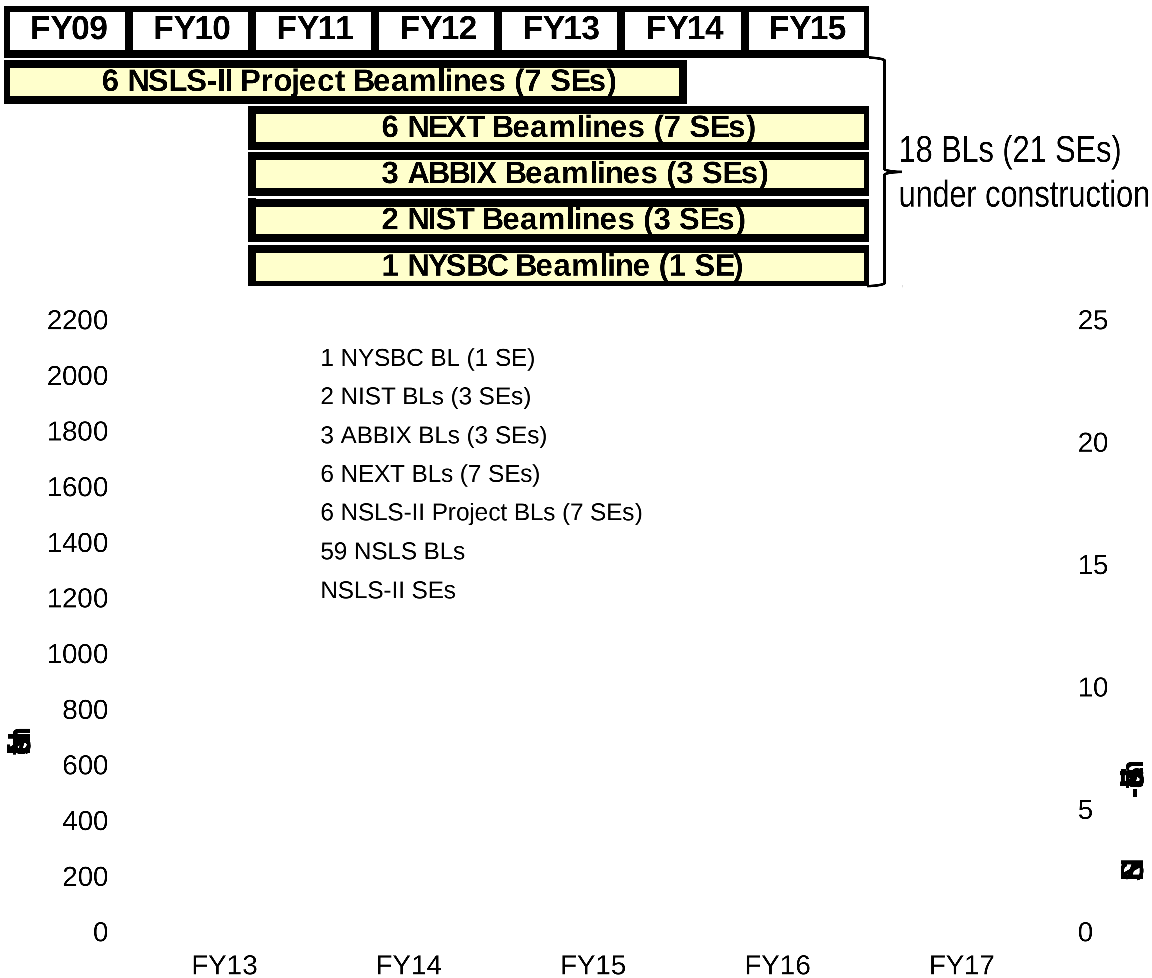
Accelerator Operations Ramp Up

	FY14	FY15	FY16
	1000 Hrs	3500 Hrs	5000 Hrs
	200 mA	350 mA	500 mA
	70 %	85 %	95+ %

Initial tasks limiting user hours

- Shake-out & conditioning of accelerator
- ID installation
- Beamline commissioning

NSLS-II Beamlines and Users



SEs = Simultaneous Endstations

- NSLS stops when NSLS-II starts in mid-FY14
- Rapid ramp up of NSLS-II beamlines for delivering new capabilities and accommodating user community
- Identified transition paths for NSLS beamlines & programs to NSLS-II beamlines
- NSLS-II will host
  - ~ 300 users with 7 SEs in FY 15
  - ~ 600 users with 21 SEs in FY16
  - ~ 1400 users with 21 SEs in FY17 (more if additional beamlines are funded)

Life Sciences Workshop

Date: 15-16 January 2008
Location: Berkner Hall
Attendees: 72

<u>Organizers:</u> Lisa Miller, Bob Sweet, Mark Chance, Vivian Stojanoff, Marc Allaire, Lin Yang, Chris Jacobsen, John Sutherland

ans for each research community (MX, SAXS, XAS, FTIR, STXM, DEI, CD, CDI, MRT)
- Lab space, ancillary facilities discussion
- Breakout sessions (MX, SAXS, Imaging)
- Funding
- Report writing for White Paper

NIH Workshops and Advisory Group

NCRR/NIGMS NSLSII Working Group

Joint study to examine opportunities for Life Sciences at NSLS-II

Meeting in Bethesda	27-28 April 2008
Working group report	8 August 2008

Workshop on Future Life Sciences Synchrotron Research at NSLS-II

Meeting in Bethesda	4-5 June 2009

NIH Advisory Group for NSLS-II Beamline Development

Initial meeting	24 May 2010
NSLS-II presentations	24 February 2011

Beamline Development Proposals

- **Project Beamlines:**
  - Development in progress
  - 4 of 6 have biology components (mostly minor)

- **Response to 2010 Call:**
  - 54 Beamline Development Proposals received and reviewed by SAC
  - 31 Type I approved, 3 Type II approved, 20 Type I not approved
  - Funding and designs in progress for some
  - 13 of 34 for biology, at least in part

- **Response to 2011 Call:**
  - 14 Beamline Development Proposals received
  - Reviews by SAC panels in November/December
  - 4 of 14 for biology

Macromolecular Crystallography

Acronym	Application	Spokesperson or Beamline Scientist	Source
	Approved 2010 Proposals		
FMX	**Frontier macromolecular crystallography**	**Robert Sweet**	**U**
AMX	**Automated macromolecular crystallography**	**Dieter Schneider**	**U**
NYX	**NYSBC microdiffraction beamline**	**Wayne Hendrickson**	**U**
SM3	Correlated spectroscopy and MX	Allen Orville	3PW
	2011 Proposals		
HMX	High-energy macromolecular crystallography	Vivian Stojanoff	U
LAX	Low-energy anomalous x-ray diffraction	Wayne Hendrickson	U

U = undulator; 3PW = three-pole wiggler

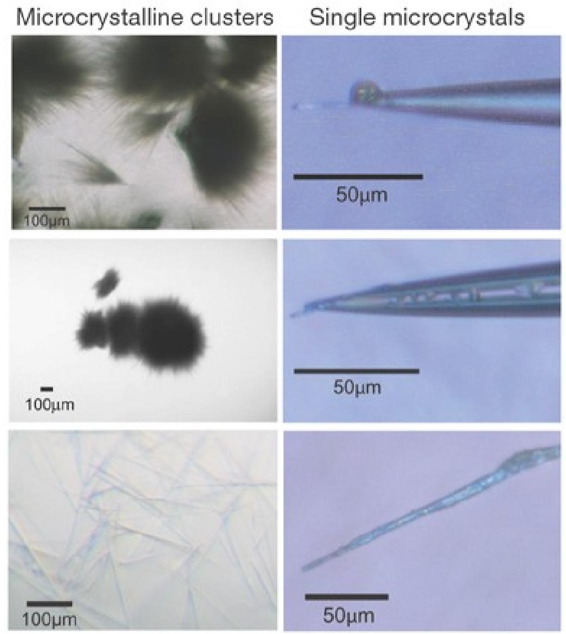
Frontier Macromolecular Crystallography (FMX)

FMX at NSLS-II:

- This MX beamline will exploit the finest properties of NSLS-II and push the state of the art in x-ray optics.
- The tunable, one micron, variable divergence beam handles small crystals, and very large unit cells.
- Preserving beam coherence makes new experiments possible.
- Cryogenic automation at the state of the art provides convenience for users.

Examples of Science Areas & Impact:

- STRUCTURAL BIOLOGY: The most interesting structures are often the most difficult. This beamline will push new limits in crystal size.
- BIOCHEMISTRY: Knowledge of intermediates in enzymatic pathways expands our understanding of cellular and microbiological processes.
- PHYSIOLOGY AND MEDICINE:Knowing how drugs interact with their targets is essential to development of improved and new pharmacologically effective compounds.



Crystals of β amyloid, which are always long and very thin.

From: Sawaya MR, Sambashivan S, Nelson R, Ivanova MI, Sievers SA, Apostol MI, Thompson MJ, Balbirnie M, Wiltzius JJ, McFarlane HT, Madsen AØ, Riekel C, Eisenberg D. Nature 447, 453-7 (2007).

Beamline Capabilities:

TECHNIQUE: Macromolecular Crystallography

SOURCE: Canted U21 In-vacuum Undulator

ENERGY RANGE / RESOLUTION: 5-20 keV; $\Delta E/E \sim 5\times10^{-4}$

BEAM SIZE: from 1x1 to 100x100 μm^2.

Diffraction Resolution to 1 Å

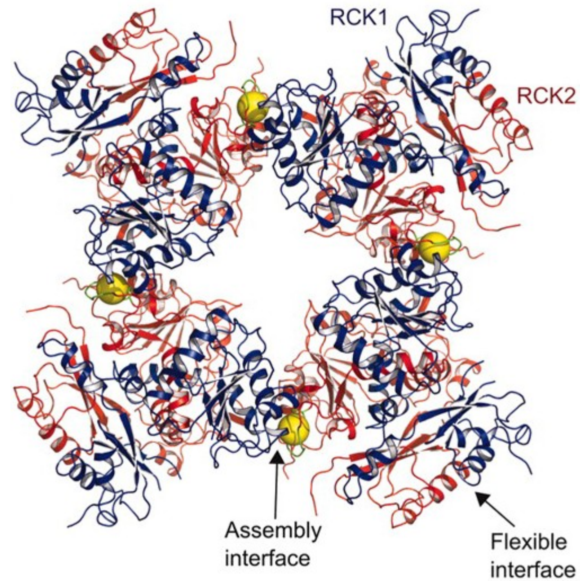
Flexible Access and Highly Automated Beamline for Macromolecular Crystallography (AMX)

AMX at NSLS-II:

- Will provide structural biologists with ready access to an advanced facility for precise structure determinations at unprecedented rates
- Will optimally exploit the unique source characteristics and deliver a very high flux in a suitably small focused beam
- Will be highly automated to support remote access and extensive experimental studies

Examples of Science Areas & Impact:

- STRUCTURAL BIOLOGY: Atomic structures of large protein and nucleic acid complexes, including membrane proteins, are prerequisites to gaining insights into their function, interaction, and dynamics, thus creating molecular movies
- BIOCHEMISTRY: Structural analysis of all intermediates in entire enzymatic cycles and pathways will expand our understanding of cellular and microbiological processes
- PHYSIOLOGY AND MEDICINE: Crystallographic studies of the interactions of drugs with their targets are essential in the development of improved and new pharmacologically effective compounds



Ribbon diagram of the gating ring of the human BK channel Ca-activation apparatus. This channel encodes negative feedback regulation of membrane voltage and Ca-signaling, which plays a central role in numerous physiological processes.

P.Yuan, MD Leonetti, AR Pico, Y Hsiung and Roderick MacKinnon, *Science 329, 182-6 (2010).*

Beamline Capabilities:

TECHNIQUE: Macromolecular Crystallography

SOURCE: Canted U21 In-vacuum Undulator

ENERGY RANGE / RESOLUTION: 5-20 keV; $\Delta E/E \sim 5 \times 10^{-4}$

SPATIAL RESOLUTION: Beam size from 5 to 300 µ
Diffraction Resolution to 1 Å

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Dieter Schneider

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NYSBC Microdiffraction Beamline (NYX)

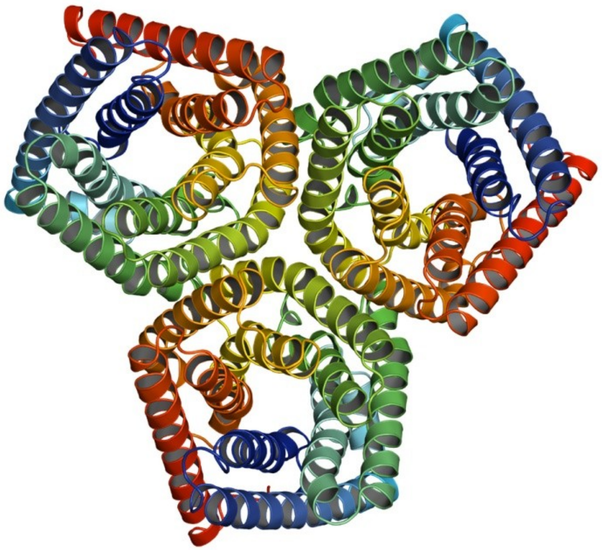
Opportunities for NYSBC Science at NSLS-II:

- Diffraction from micron-sized crystals and rastered scans for optimized diffraction from larger crystals of challenging biological macromolecules and complexes
- Access to a broad range of resonant edges for anomalous diffraction (MAD and SAD) phasing, from U M_V (3.5 keV) to Se K (12.7 keV) to U L_{III} (17.2 keV)
- Optimization of anomalous scattering from high energy resolution for sharp transitions at resonant edges and lower energy for increased f '' with light elements (sulfur)

Example Science Areas and Impact:

- MEMBRANE PROTEINS: Challenging structural problems with high relevance in neurobiology & metabolic disorders
- MACROMOLECULAR COMPLEXES: Protein-protein interactions in signaling complexes and protein-nucleic acid complexes in transcription or replication
- METHODS DEVELOPMENT: Supports efforts for methods to improve phase evaluation and enhance resolution

New York Structural Biology Center (NYSBC) hosts dozens of investigator groups at ten premier institutions



Homolog structure of the SLAC1 anion channel for closing stomata in leaves. Here the trimeric channel protein is shown as viewed from outside the membrane of a guard cell. Each protomer is colored spectrally from the amino-terminus (blue) to carboxy-terminus. Chen et al., *Nature* **467**,1074 (2010).

Beamline Capabilities:

TECHNIQUE: Macromolecular Crystallography

Source: Undulator on a low-β straight section

BEAM CROSS-SECTION: 5 μ - 50 μ

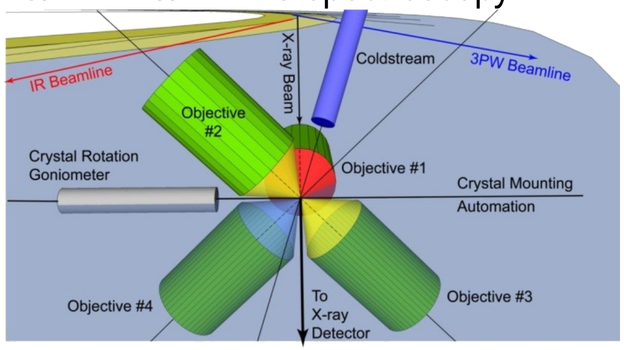
ENERGY RANGE: 3.5 – 17.5 keV

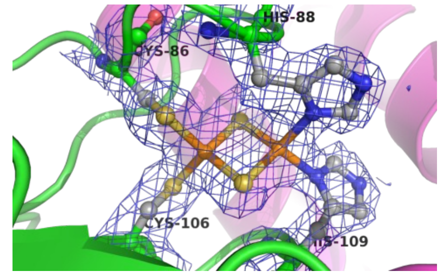
ENERGY RESOLUTION: $\Delta E/E \sim 5 \times 10^{-5}$

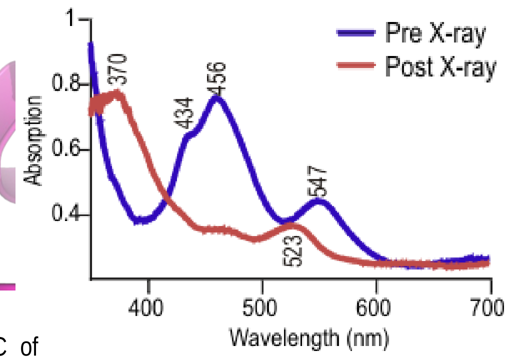
Correlated Spectroscopy and MX (SM3)

A unique facility for multi-disciplinary, nearly simultaneous studies of single crystals

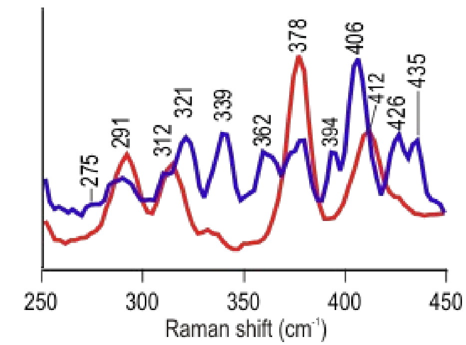
- Macromolecular crystallography
- Electronic absorption spectroscopy
- Fluorescence spectroscopy
- Raman spectroscopy
- FTIR spectroscopy
- XAS/XANES/EXAFS spectroscopy







Correlated studies conducted at X26-C of NSLS have demonstrated the reduction of the iron-sulfur Rieske center in Stachydrine demethlyase. The protein structure obtained with MX gives no information on this X-ray induced process. Comparison of the pre and post X-ray exposure absorption (top) and Raman (bottom) spectra, however, do provide clear evidence of this reduction. K. Daughtry, et al., in preparation .



Examples of Science Areas & Impact

Redox state: Define redox states of metalloproteins using structures and spectroscopy from the same sample

Mystery density: Raman spectroscopy helps assign electron density where ambiguities exist

Photochemistry: Initiate and follow reactions

Mechanisms: Trap and identify reaction intermediates

Beamline Capabilities:

Techniques: Macromolecular crystallography, Spectroscopy on- and off-beamline (UV/vis, Fluorescence, IR, Raman, XAS and EXAFS)

Source : Three-pole wiggler

Energy Range: 5-20 keV

Flux: 10^{13} ph/s at 12 keV

Allen Orville

Ultrafast Data Collection on AMX

	X29 at NSLS	X25 at NSLS	AMX at NSLS-II
Beamline Flux	4 x 10^{11} ph/s	4 x 10^{11} ph/s	2 x 10^{13} ph/s
Detector Technology	CCD Composite	Pixel Array	Advanced PAD
Detector	ADSC 315r	Pilatus 6M	**Eiger or ADSC DMPAD**
Data Set Format	180 frames of 1°	900 frames of 0.2°	900 frames of 0.2°
Exposure Time / Frame	2 s	0.4 s	8 ms
Dead Time / Frame	1 s	2 ms	**2 µs**
Framing Rate	0.5 Hz	2.5 Hz*	**125 Hz**
Time / Data Set	540 s = 9 min	360 s = 6 min	7.2 s

*) maximal framing rate = 24 Hz

Advanced new detectors are required for full design performance

Critical parameters:
µs dead time,
kHz framing rate

Automounter Requirements

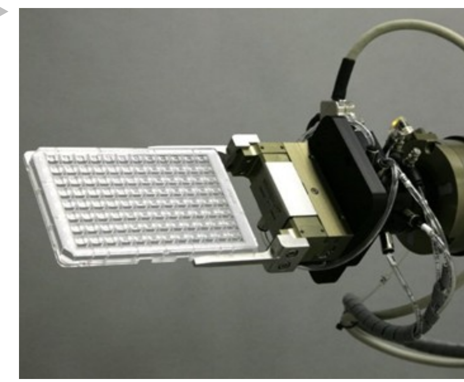
Basic requirements:

- <u>Handle mounted crystals</u>

  in common pucks and — Unipuck, ALS puck (no vials)
  less common formats — ESRF basket, Actor puck (in vials)

Actor, ALS, and Unipuck

- <u>Handle crystallization well plates</u> and similar devices



Greiner 96-well crystallization plate

Maximal specimen processing rates:

Specimen mounting	6 s
Automatic crystal centering	20 s
Data collection within	10 s
Maximal throughput	100 crystals / h
In a 12 hour shift	1200 crystals
	75 pucks in 10 shipping dewars

Biological Scattering

Acronym	Application	Spokesperson or Beamline Scientist	Source
	NSLS-II Project Beamlines		
CHX	**Coherent hard x-ray scattering**	**Andrei Flueresu**	**U**
IXS	**Inelastic x-ray scattering**	**Yong Cai**	**U**
	Approved 2010 Proposals		
LIX	**X-ray scattering for life sciences**	**Lin Yang**	**U**
ABS	Automated biomolecular solution scattering	Lin Yang	3PW

U = undulator; 3PW = three-pole wiggler

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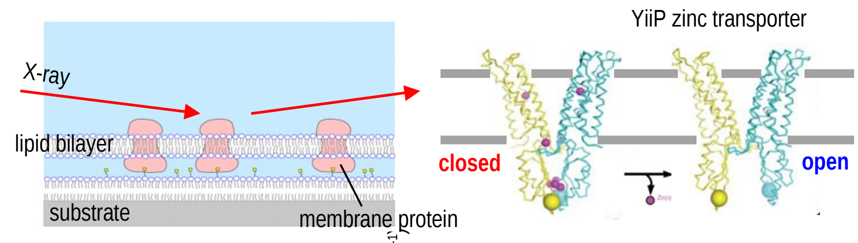
High Brightness X-ray Scattering for Life Sciences (LIX)

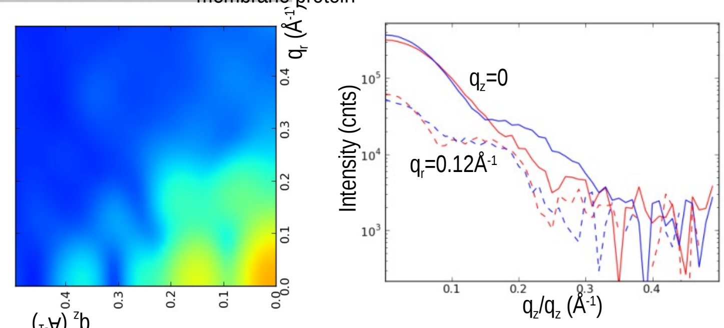
LiX at NSLS-II:

- Time-resolved X-ray scattering measurements of proteins and DNA/RNA in solution using flow cells on time scales down to 10µs
- Grazing incident scattering from 2D solutions of membrane proteins embedded in near-native membranes
- 1µm beam scanning probe imaging and tomography of biological tissues

Examples of Science Areas & Impact:

- PROTEIN DYNAMICS: Help understand the dynamic processes of protein conformation change (e.g. folding) and enzymatic reaction
- MEMBRANE PROTEINS: Resolve the structure of membrane proteins at low resolution; Reveal how the structures of these proteins change in response to external stimuli
- TISSUE ENGINEERING: Help elucidate the relationship between the hierarchical structure in natural and engineered tissues and their functional properties.





A unique capability of the LiX beamline is to collect scattering data from membrane proteins embedded in near native membranes. This is the two-dimensional analogue of the solution scattering technique that has been very successful for soluble proteins in recent years. This figure shows simulated data from YiiP in DOPC bilayer in open and closed states. Simulated noise, based on estimated scattering cross-section, has been added in the line cuts (lower right).

Beamline Capabilities:

TECHNIQUES: Micro-beam, simultaneous small and wide angle X-ray, transmission and grazing incidence

SOURCE: undulator (U23)

ENERGY RANGE / RESOLUTION: 4-20keV @ 0.01%

Q RANGE: 0.002-3.0Å^{-1} @ 12keV

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Lin Yang

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Biological Spectroscopy

Acronym	Application	Spokesperson or Beamline Scientist	Source
	NSLS-II Project Beamlines		
SRX	**Sub-micron resolution x-ray spectroscopy**	**Juergen Thieme**	**U**
	Approved 2010 Proposals		
AIM	Advanced infrared microspectroscopy	Lisa Miller	BM
SM3	Correlated spectroscopy and MX	Allen Orville	3PW
XAS	X-ray absorption spectroscopy	Mark Chance	3PW
XFP	X-ray footprinting	Mark Chance	DW

BM = bending magnet; DW = damping wiggler; U = undulator; 3PW = three-pole wiggler

Biological Imaging

Acronym	Application	Spokesperson or Beamline Scientist	Source
	NSLS-II Project Beamlines		
HXN	**Hard x-ray nanoprobe**	**Yong Chu**	**U**
SRX	**Sub-micron resolution x-ray spectroscopy**	**Juergen Thieme**	**U**
	Approved 2010 Proposals		
CDI	Coherent x-ray diffraction	Ian Robinson	U
FXI	**Long beamline for full-field imaging**	**Jake Socha**	**SCW**
IRI	Full-field infrared spectroscopic imaging	Lisa Miller	BM
XFM	X-ray fluorescence microprobe	Antonio Lanzirotti	3PW
	2011 Proposals		
MIT	Medical imaging and radiation therapy	Avraham Dilmanian	SCW
STX	Scanning transmission x-ray microscope	Juergen Thieme	BM

BM = bending magnet; SCW = superconducting wiggler; U = undulator; 3PW = 3-pole wiggler

ABBIX

Advanced **B**eamlines for **B**iological **I**nvestigations with **X**-rays

FMX	Frontier Macromolecular Crystallography (MX)
AMX	Flexible Access and Highly Automated MX
LIX	High Brightness X-ray Scattering for Life Sciences

NEXT: **N**SLS-II **EX**perimental **T**ools

ESM	Electron spectromicroscopy
FXI	Full-field x-ray imaging
ISS	Inner shell spectroscop
ISR	In-situ and resonant hard x-ray studies
SIX	Soft inelastic scattering
SMI	Soft matter interfaces

ABBIX

Advanced **B**eamlines for **B**iological **I**nvestigations with **X**-rays

Ab Ex

Abstract **Ex**pressionist New York: the Big Picture

Museum of Modern Art October 2010

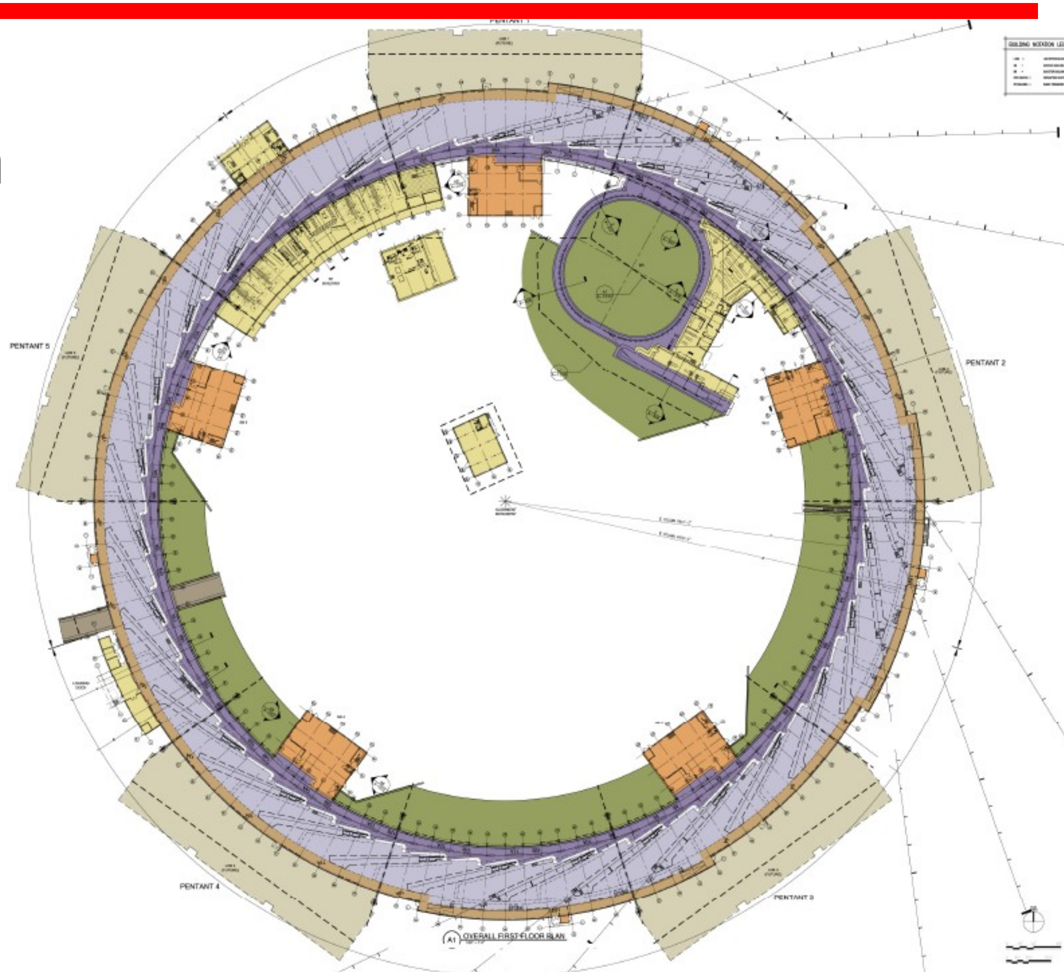
Number 1A, Jackson Pollock (1948)

NIH Support for NSLS-II Beamlines

- **NIH Advisory Committee Definitions**
  - Initial suggestions: 2 MX, 1 Scattering, 1 Imaging ID beamlines
  - Ultimate endorsement: 2 MX, 1 SAXS/WAXS
- **Relevant Beamline Development Proposal (BDP) Options**
  - FMX and AMX for MX
  - LIX for scattering
  - CDI and FXI for imaging
- **NSLS-II Development of NIH specified BDPs**
  - MOU & IAA established in 2010 for ARRA funding of IDs $12.0M
  - MOU established in August 2011 for FMX/AMX/LIX Beamlines
  - IAA finalized to transfer NIH FY11 funding 23.4M
  - Future NIH funds: FY12 $5.5M + FY13 $4.1M = 9.6M
  - NSLS-II: Common Beamline Components 3.0M
  - **Total** $48.0M

ABBIX: Biology’s Bright Future at NSLS-II

NSLS-II Design Features



Design Parameters

- 3 GeV, 500 mA, top-off injection
- Circumference 791.5 m
- 30 cell, Double Bend Achromat
    - 15 high-β straights (9.3 m)
    - 15 low-β straights (6.6 m)

Novel design features:

- Damping wigglers
- Soft bend magnets
- Three pole wigglers
- Large gap IR dipoles

Ultra-low emittance

- $\varepsilon_x, \varepsilon_y$ = 0.6, 0.008 nm-rad
- Diffraction limited in vertical at 12 keV
- Small beam size: σ_y = 2.6 μm, σ_x = 28 μm, σ'_y = 3.2 μrad, σ'_x = 19 μrad

Pulse Length (rms) ~ 15 psec

X-ray Footprinting (XFP)

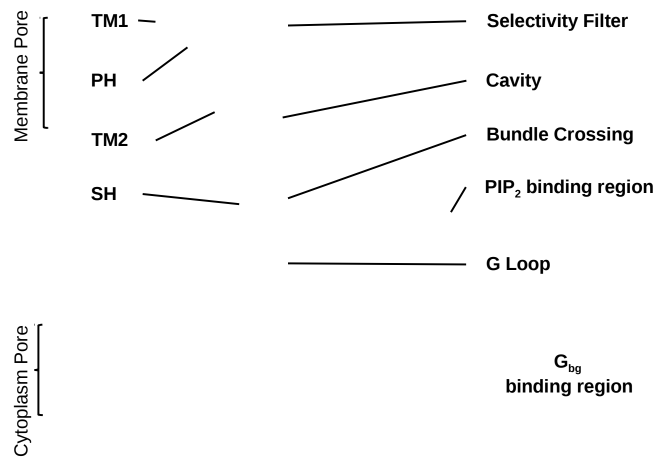
XFP at NSLS-II:

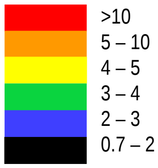
- X-ray mediated hydroxyl-radical footprinting (XFP) will provide a local probe of solvent-accessibility for *in-vivo* and *in-vitro* structural studies of biomolecular complexes and their interactions.
- Time-resolved XFP studies to elucidate local structural dynamics from microsecond to millisecond time scales.
- The high flux density and beam energy range of NSLS-II DW will provide high quality data from microliter volumes of dilute solution samples in near physiological conditions.

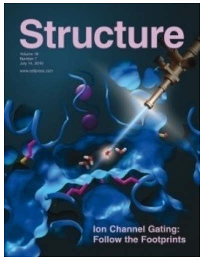
Examples of Science Areas & Impact:

- ***IN VIVO STUDIES***: Real time ribosomal biogenesis in living cell, cell surface receptor-ligand interactions (drug/protein, antibody/antigen).
- ***MEMBRANE PROTEINS***: Understanding of structure and function at molecular level for ion channels, receptors (GPCR), gated pores, H^+-pumps, transporters, membrane enzymes, dynamics of bound waters in pores, channels and cavities.
- ***MEGA DALTON COMPLEXES***: XFP provides structural information for intermediates and activated states of extremely large complexes (e.g. cell cytoskeleton, proteosome assemblies).
- ***HYBRID APPROACH***: XFP (local structural measures) along with SAXS (global) is important in deciphering the mechanism of biomolecular assemblies in a "Biology Village" life sciences mode at NSLS II.

Exploring the K^+ channel gating







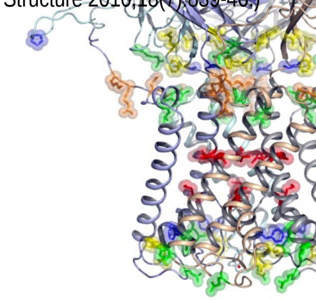
Closed and open states of KirBac3.1 are irradiated with focused 'white beam' of beamline X28C of NSLS. The chemical modification mediated by the hydroxyl radical on the protein side chains are analyzed by high resolution mass spectrometry. The relative rate of modification between these two states are directly correlated to the changes solvent accessibility of residue undergoing modofications. This study has allowed the identification of **novel gating-sensitive residues** in the permeation pathways of the channel and also **residues that mediate the gating process through allosteric conformational rearrangements**.(Gupta et al. Structure 2010,18(7):839-46.)

Beamline Capabilities:

TECHNIQUE(S): Steady state and time-re radical mediated Protein and Nucleic Aci

SOURCE: Damping Wiggler

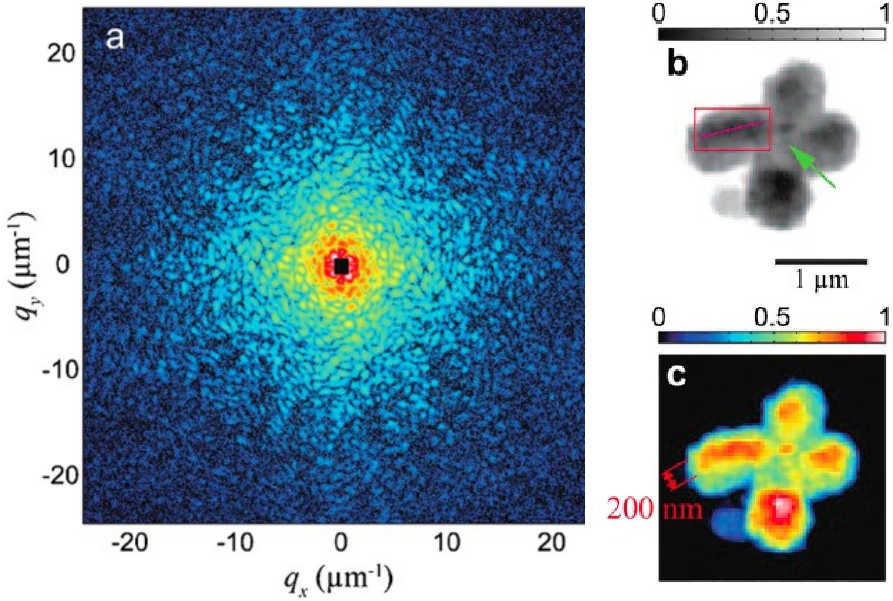
ENERGY RANGE / RESOLUTION: "Whit



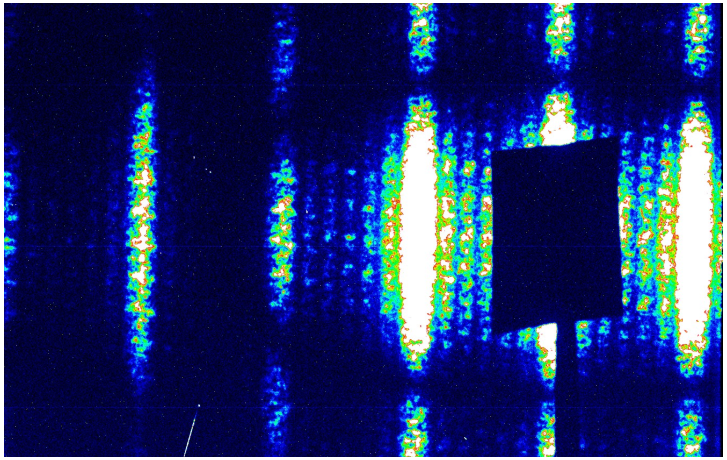
Coherent Diffraction Imaging (CDI)

CDI at NSLS-II:

- Diffraction imaging of crystal shapes in 3D on nm scale
- Diffraction imaging of cryo-frozen cells and tissues
- Imaging of strain fields inside crystals
- Time evolution of shape/strain under working conditions
- Manipulation/deformation/indentation on the nm scale
- Ptychographic imaging for domains in materials
- Ptychographic imaging of biological samples using phase contrast, dark-field and phase encoding methods
- Applications in nanoscale semiconductor devices, strain engineering, catalysis and energy materials



CDI imaging of a human chromosome, Y. Nishino et al PRL 102, 018101 (2009)



Collagen Phase-plate diffraction, Felisa. Berenguer and Richard Bean

CDI Beamline Capabilities:

IUV20 undulators low-β

Both in-line and Bragg CDI

Long hutch, stable floor

Monochromatic beam 2.5-20 keV (in-line CDI)

Cryo sample manipulation in vacuum

KB optics and ultra precise goniometer

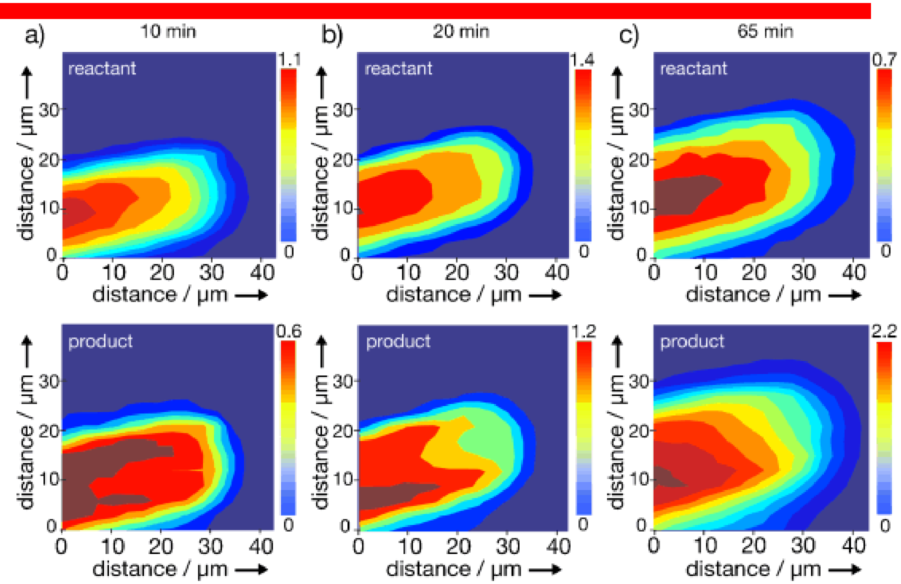
Full-Field Infrared Spectroscopic Imaging (IRI)

IRI at NSLS-II:

- Will enable in-situ studies of organic composition of materials by vibrational spectroscopy
- Measurements from microseconds to days with micromolar detection sensitivity and sub-micron spatial resolution
- The combination of the high brightness and low noise of NSLS-II with a high throughput imaging system will be world leading

Examples of Science Areas & Impact:

- CATALYSIS: In zeolite catalysis, simultaneously image reactants and products in real time for a mechanistic picture of in situ zeolite reaction chemistry
- POLYMERS: In polymer-fiber composites, image the interface morphology under sheer and stretch conditions in situ
- MICROBIOLOGY: In cellulose degradation by bacteria, rapidly image reaction location, rate, and chemical intermediates for improved biofuel production
- MEDICINE: In Lou Gehrig's disease, simultaneously image the formation, structure, and associated cellular toxicity of intracellular superoxide dismutase aggregates



Raster scanned infrared images of a zeolite crystal reacted with 2-chlorothiophene after a) 10, b) 20, and c) 65 min of reaction for the 1412 cm^{-1} reactant band (top) and 1401 cm^{-1} product band (bottom). IRI will enable real-time imaging at much faster time scales without raster-scanning. M. Kox et al., *Angewandte Chemie*, 48, 8990 (2009).

Beamline Capabilities:

TECHNIQUE(S): Fourier transform infrared spectroscopic imaging with a 64x64 focal plane array detector

SOURCE: Dual dipole magnets

ENERGY RANGE / RESOLUTION: 500 – 4000 cm^{-1} / 1 cm^{-1}

SPATIAL RESOLUTION: ~1 – 5 μm with pixel oversampling and image deconvolution